Biologisch Laboratorium, Vrije Universiteit Amsterdam, Nederland

Soil microarthropods as indicators of soil acidification and forest decline in the Veluwe area, the Netherlands

Nico M. van Straalen, Michiel H. S. Kraak and Carl A. J. Denneman

With 6 figures

1. Introduction

Air pollutants are one of the causative agents in the presently seen forest decline syndrome, but the mechanisms of action are incompletely known. The classical acid rain hypothesis states that deposition of air pollutants contributes to soil acidification, loss of plant nutrients and mobilization of aluminium (Ulrich, 1983). In various areas, acidification of soils induced by atmospheric deposition indeed surpasses the internal rate of proton production (van Breemen et al., 1984). This soil-centred theory is often presented as an alternative to the direct damage caused by the action of reactive air pollution components on the leaves (Arndt et al., 1982). Since diagnostic fertilization may reduce the symptoms of forest decline (Hüttl, 1985), it is clear that nutrient shortage, either induced by leaf damage, or by soil impoverishment, is of particular importance. To discriminate between the various theories of forest decline, one might argue that, if forest decline is at least partly due to processes occurring in the soil, the deterioration will be accompanied by changes in the soil microfauna composition, because of the intimate contact of soil animals with the soil. In this paper we investigate the relation between forest vitality, soil chemistry and the density of microarthropods.

A number of authors have described changes in the soil fauna community as a consequence of artificially applied acid rain (Bååth et al., 1980; Hågvar & Amundsen, 1981; Hågvar, 1984; Heungens & van Daele, 1984). These studies demonstrate that rearrangement of the community, induced by soil acidification, may be very complicated. Among Collembola, the species *Isotoma notabilis* appeared to be sensitive to acidification, and could possibly serve as an indicator species. However, some of the results of these studies are in apparent conflict with each other (*cf.* Hågvar, 1984; Heungens & van Daele, 1984). This could be due to circumstances specific for the studied sites, or to the rate of acidification under artificial acid rain.

In this paper we try to resolve the problem by means of a comparative approach, thus avoiding possible effects specific to one site, and effects from artificial acidification. We selected various forest stands of differing vitality, within an area of restricted size, which are about equally exposed to air pollution. To maximize the applicability of the approach, we focussed attention on easily recognizable arthropods, and expressed their population density as a percentage of the total density of the group to which they belonged; as argued by Clausen (1986), relative population densities may be better indicators of pollution than absolute densities. On the basis of the results, we argue that monitoring of sensitive soil microarthropods (indicator species), in connection with chemical analysis, may contribute to judging the probable vitality development of a pine stand in a relatively early stage.

2. Material and methods

2.1. Site selection

In May 1985, 12 stands of *Pinus sylvestris* L. were selected, out of 22 inspected, within the Veluwe area in the Netherlands. The stands differed in vitality but were otherwise more or less equal with respect to age (> 20 years), soil type (podzol developed on sand), and ground vegetation (mainly consisting of *Avellana flexuosa* TRIN., *Vaccinium*
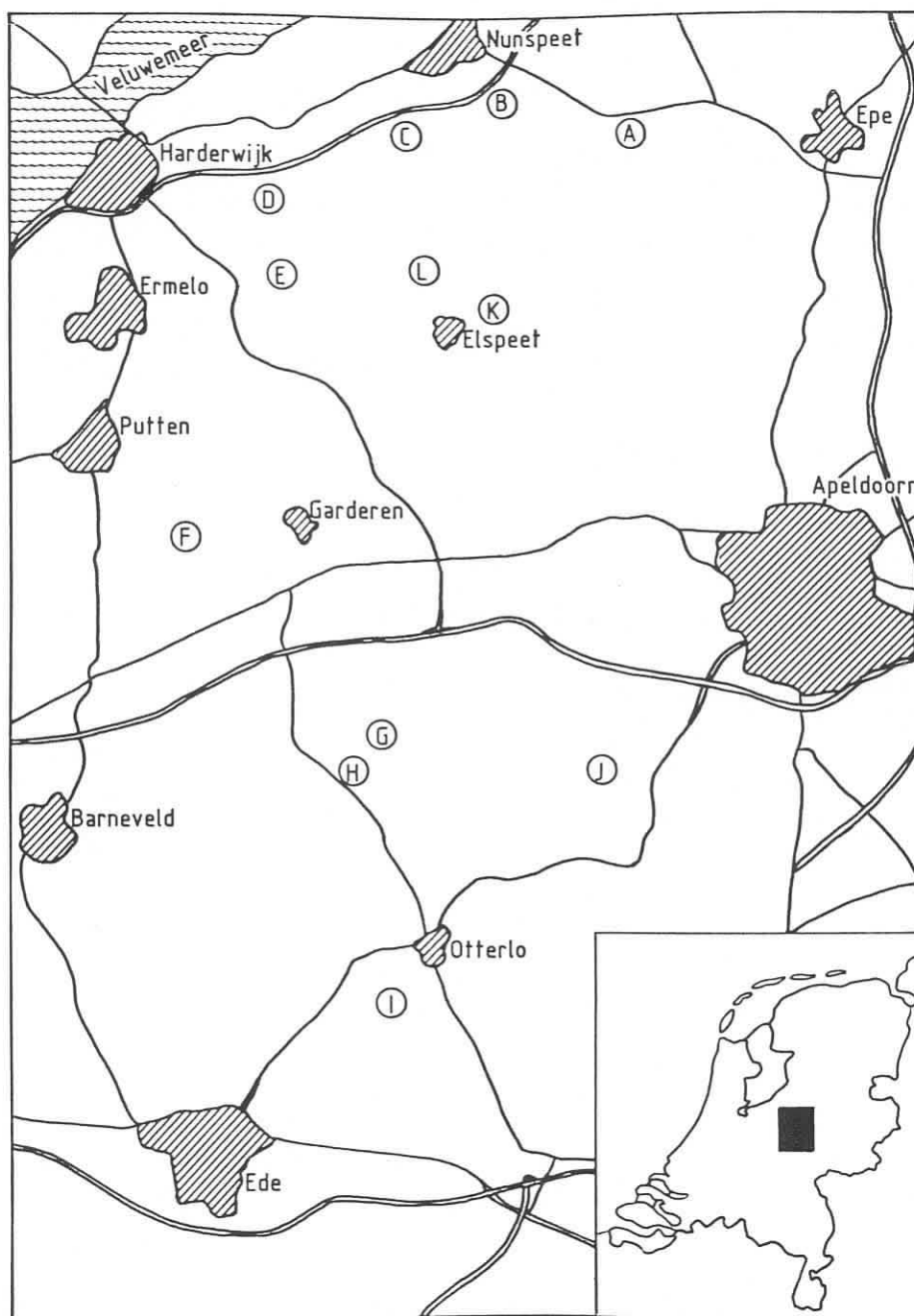

Fig. 1. Map of the Veluwe area, showing the locations of sampling sites. The inset shows the Netherlands.

myrtillus L., *Dicranum scoparium* HEDW. and *Hypnum cupressiforme* L.). Vitality of a forest was judged on the basis of the monitoring program of the Netherlands State Forest Management (Anonymous, 1984), as well as on own observations. Fig. 1 shows a map of the locations.

In each stand, a representative plot (20 m × 20 m) was delineated, and 15 random core samples were taken in the plot, by means of a split-corer (∅ 10 cm). Sampling was confined to the litter-fermentation layer of the soil profile (A_{00}-A_0 horizons combined); the depth of this layer was measured for each core, after opening the corer. For each plot, 3 cores were used for soil chemistry aspects and 12 were extracted for microarthropods (see below). Vitality of the plot was measured as the number of year-classes of green needles in the crown of each of 10 randomly selected trees, using the scale: 1/2, 3/4, ... 2½. Each tree was judged by 3 people from different points of view.

2.2. Soil chemistry

Each core was homogenized and pH was measured in a water extract of the fresh material (20 g sample + 200 ml deionized water, shaken for 2 h). From each core, 2 × 100 mg of oven-dried material was digested completely in a $HNO_3/HClO_4$ mixture (7:1). Concentrations of K, Ca, Mg, Fe and Mn in the diluted digests were determined by flame atomic absorption spectrometry (Perkin Elmer 4000). Aluminium was determined in the digests by means of a colorimetric method (methylthymolblue, following reduction of Fe by ascorbic acid). Total amounts of carbon and nitrogen were determined by elemental analysis on 1 mg of oven-dried material (Carlo Erba 1106). On each of the 3 replicate cores from a plot, determinations were done in duplicate, which, in the data analysis, were combined to a single observation for a core.

2.3. Soil fauna

Arthropods were extracted from the cores by means of Tullgren-type equipment (VAN STRAALEN & RIJNINKS, 1982). The extracted fauna was identified to groups recognizable under a dissecting microscope (magnification 20−40×). Total numbers of the orders Collembola and Oribatida were recorded for each core, as well as the numbers of the families Pelopidae, Damaeidae, Camisiidae, Phthiracaridae, Onychiuridae, Poduridae, Isotomidae and Sminthuridae. *Platynothrus peltifer* KOCH (Oribatida) and *Isotoma notabilis* SCHÄFFER (Collembola) were recorded at the species level. Identification followed SELLNICK (1960) and GISIN (1960). Counts of microarthropods were expressed as numbers per core, and as a percentage of the total count of oribatids or Collembola in the same core.

2.4. Data processing

The following rationale was applied in searching for patterns in the data:
1. Each variable was subjected to one-way analysis of variance, to test for differences between sites, regarding differences between cores within a site as sampling error. If necessary to achieve homogeneous variance, transformations were applied to the data. The logarithmic transformation was used for counts, and the arcsine transformation for percentages (SOKAL & ROHLF, 1981).
2. For variables showing significant differences between sites, a pooled value was calculated for each site. If a variable had been transformed, the pooled value was calculated from the untransformed data, and was then transformed. These averages (12 for each variable) were tested for correlations with each other (Pearson's test, twotailed).
3. From the variables showing one or more significant correlations with other variables, a cluster of variables was selected, which were correlated with each other, as well as with vitality. On this cluster the main conclusions were based.

3. Results

Vitality of the various tree stands, as judged by the number of needle year-classes in pine trees, is given in table 1. Taking the introduced genotypes and local factors into account, the presence of two year-classes is considered normal for *Pinus sylvestris* stands in the area (Anonymous, 1984). Our survey was made in early spring, before budding of that year's needles. In late summer, the number of year-classes is about 1/2 higher (unpublished observations). Given these conditions, it

Table 1. List of the investigated sites, their codes, and the vitality of their tree stands, as judged by the mean number of needle year-classes in May 1985, with standard deviations based on 10 trees per site

site code	local name of forest	needle year-classes ± sd	
A	Landgoed Welna	1.35 ± 0.41	a
B	Boswachterij Nunspeet	0.85 ± 0.34	b
C	Willemsbos	0.93 ± 0.24	b, c
D	Leuvenhorst	1.10 ± 0.21	a, c
E	Leuvenumse bos	1.00 ± 0.00	b, c
F	Sprielder bos	1.25 ± 0.35	a, c
G	Boswachterij Kootwijk	0.90 ± 0.21	b
H	Loobos	0.85 ± 0.23	b
I	Westerrode	0.88 ± 0.18	b
J	Boswachterij Hoenderloo	1.03 ± 0.30	b, c
K	Elspeter bos	0.88 ± 0.21	b
L	Stakenberg	0.85 ± 0.21	b

Note: Means sharing a common letter (a, b, c) do not differ significantly at the 5 % level.

appears from table 1 that one half of the investigated pine stands have low vitality (sites L, H, B, K, I and G). In fact only the stands at sites (A, F and D) can be considered as clearly vital, while those at sites E, J and C take an intermediate position.

Table 2 provides a survey of soil variables which did not differ significantly between the sites, while table 3 lists the variables that did show significant differences. Comparing these tables, it appears that the sites form a rather homogeneous set with respect to the elements Ca, Mg and Fe, but are different in the elements K and Mn. The pH does not differ: all soils are equally acid. The

Table 2. List of soil variables not differing significantly between sites

variable	mean ± sd	units
depth litter layer	6.2 ± 1.3	cm
pH (H$_2$O)	3.7 ± 0.1	–
Ca	30.7 ± 9.1	μmol/g
Mg	12.2 ± 2.2	μmol/g
Fe	52.8 ± 11.6	μmol/g
Al	16.5 ± 2.2	μmol/g

Note: Means and standard deviations were based on observations from all sites combined. All variables refer to the A-horizon of the forest floor.

nitrogen content of the forest floor was highest for the sites A, I, F and H. Since this includes both vital (A, F) and less vital (I, H) sites, there is no clear relation of forest floor nitrogen to vitality. A similar argument holds for K.

Table 3. List of soil variables showing significant differences between sites

variable	range	units
K	4.6– 9.9	μmol/g
Mn	0.73– 2.6	μmol/g
N	0.83– 1.44	% (m/m)
C/N	22–30	–

Note: For each variable a range is given (site with lowest mean – site with highest mean). All variables refer to the A-horizon of the forest floor.

Among the variables given in table 3, the Mn concentration and the C/N ratio were significantly correlated with vitality from table 1. This is pictured in figs. 2 and 3. The most vital sites (A and F) have the highest Mn content and the lowest C/N-ratio, while the other sites are more like each other.

Among the soil fauna, almost all groups recorded showed significant differences between the sites. The densities of total Oribatida and Collembola vary from 8,000 to 80,000 per m^2 (Oribatida) and from 4,000 to 30,000 per m^2 (Collembola). There is a clear correlation between Oribatida and Collembola (fig. 4), but the density ratio (on the average 3.6:1) was not significantly correlated with vitality. It seems that the sites provide habitats which support different densities of microarthropods, for reasons not always related to the vitality of the stand. For some of the groups (notably Collembola) the depth of the litter layer could explain some of the variation. To avoid aspecific effects of site differences, we consequently expressed the density of each arthropod group as a percentage of the density of its order (Oribatida or Collembola).

From the various density ratios tested, two were significantly correlated with vitality: the number of *Platynothrus peltifer* as a percentage of the Oribatida, and the number of Sminthuridae as a percentage of the Collembola. In the two vital sites A and F, *P. peltifer* accounts for 10–20% of the density of oribatids, while in the other sites this percentage was only about 2% (fig. 5). Other oribatid groups were more abundant at these sites, but not in a consistent pattern related to vitality. Among the Collembola, the proportion taken by the family Sminthuridae varied from 9 to 65% and was correlated with vitality (fig. 6). The other main collembolan group was Isotomidae
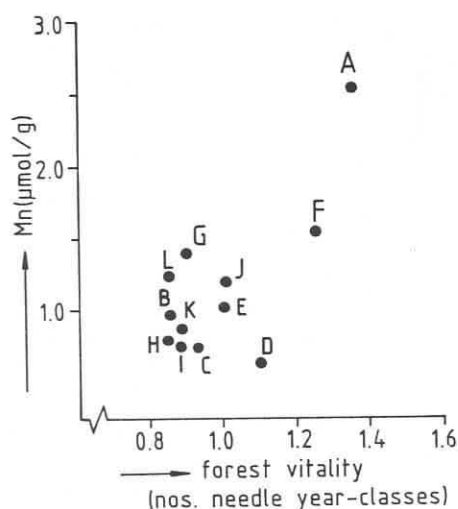
Fig. 2. Correlation between vitality and the Mn concentration of the forest floor. Each point refers to the mean of a site. For site codes see Table 1. Correlation coefficient = + 0.74.
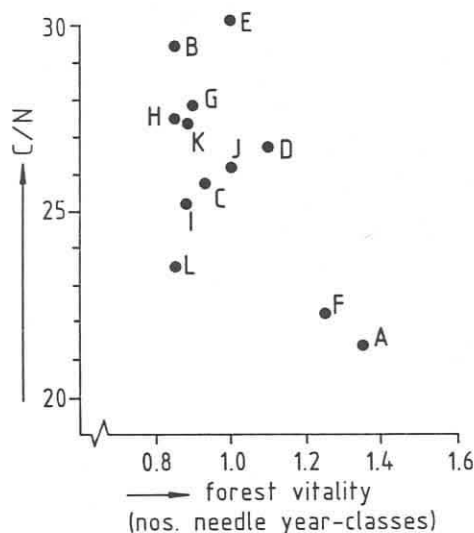

Fig. 3. Correlation between vitality and the C/N ratio of the forest floor. Each point refers to the mean of a site. For site codes see Table 1. Correlation coefficient = − 0.62.

and this family showed the opposite trend. The species *Isotoma notabilis* was present in low density at most of the sites and could therefore not serve as an indicator.

Comparing the results on microarthropods and soil chemistry, it can be concluded that, although the correlations are weak in some cases, there is a consistent pattern in the data: the soils of the most vital stands are highest in Mn, lowest in C/N, and have the highest relative population densities of *P. peltifer* and Sminthuridae.

4. Discussion

The analysis of the relations between soil microarthropods and soil fertility has a long tradition, but the application of this study to the present-day problems of acid precipitation and forest decline adds a new dimension to it. Our results have shown that, within the study area, both soil fauna and soil chemistry aspects differ between pine stands of differing vitality in a consistent manner. Therefore, we conclude that changes in the soil are at least part of the forest decline problem in the Veluwe area in the Netherlands.

Due to the inventory nature of the study, precise relations between forest vitality, soil quality and soil fauna, are still incompletely known. Among the soil chemistry aspects, the carbon/nitrogen ratio and the Mn concentration were correlated with vitality and these will be discussed first.
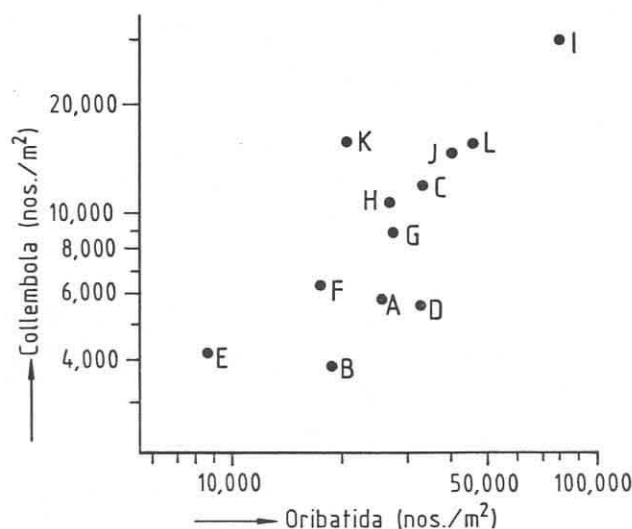
Fig. 4. Correlation between the mean population densities of Collembola and Oribatida. For site codes see Table 1. Correlation coefficient = + 0.78 (both axes logarithmically transformed).
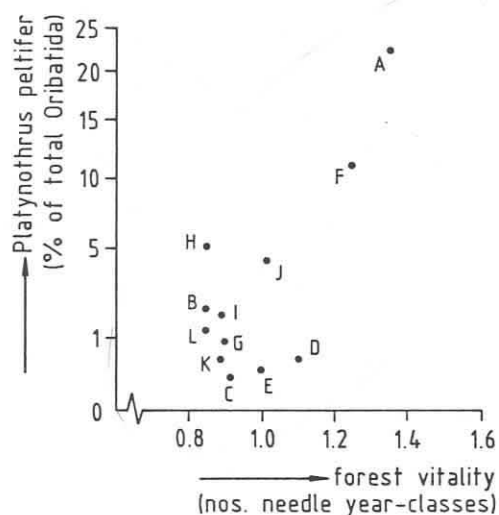

Fig. 5. Correlation between vitality and the population density of *Platynothrus peltifer*, expressed as a percentage of the total number of Oribatida. For site codes see Table 1. Correlation coefficient = + 0.75; y-axis transformed according to y = arcsin ($\sqrt{(y/100)}$).
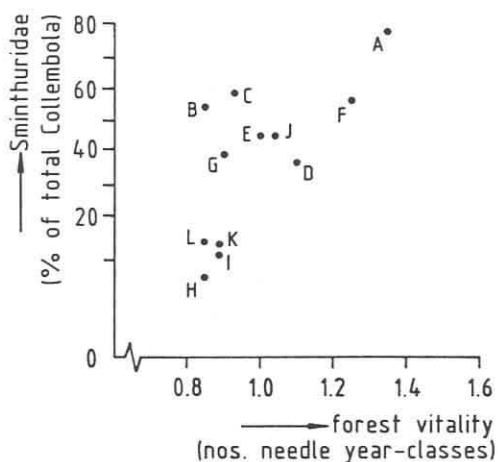

Fig. 6. Correlation between vitality and the population density of Sminthuridae, expressed as a percentage of the total number of Collembola. For site codes see Table 1. Correlation coefficient = + 0.70 (y-axis transformed as in Fig. 5).

The higher average C/N-ratio as found in the forest floor of less vital stands, may relate to a disturbance of litter decomposition at these sites. It is well known that nitrogen is conserved during the initial stages of decomposition, and that the C/N-ratio tends to decrease (SWIFT *et al.,* 1979). A high C/N ratio is therefore indicative of an over-representation of undecomposed material in the litter. Acid precipitation may inhibit microbial activity in soil (BEWLEY & STOTZKY, 1983), and this may affect both immobilization and mineralization of nitrogen, depending on the stage of decomposition of the litter (BOSATTA, 1982; KLEIN *et al.,* 1984). Since soil microarthropods take part in the nitrogen dynamics of pine needle litter by grazing microbial biomass (VERHOEF & DE GOEDE, 1985), differences in microbial activity will be parallelled by changes in the microarthropod community. Another disturbance of the nitrogen dynamics may be the ammonia emission from pig sties, chicken farms and field-spread dung, which is rather intense in the area. Pine trees exposed to deposition from these sources have an increased nitrogen content in their needles; also, litter from these places shows a disturbed pattern of decomposition and nitrogen dynamics (VERHOEF & DOREL, 1988). Effects from ammonium deposition have recently been considered as an additional explanation of forest decline (NIHLGÅRD, 1985). In our study, these emissions have probably affected all sites in an equal manner, since the non-diffuse ammonium deposition from agricultural sources does not exceed 1,200 m (ROELOFS *et al.,* 1985), and none of our sites was contiguous to a farmyard or field.

As to the manganese concentrations, the differences between sites probably reflect small differences in soil fertility. Being a relatively mobile element, Mn is one of the first nutrients (preceded by K and Mg) to leach under acidification (HOVLAND *et al.,* 1980; BROWN, 1985). Under acid conditions, there is often a net loss of Mn from a forest ecosystem, because the output by leaching is not compensated by an equal input from precipitation (ZÖTTL, 1985). It is therefore conceivable that vitality differences between sites are partly due to nutrient shortage in the soil. Litter Mn concentrations may also be influenced by the fact that Mn is among the elements accumulating in pine needles by aging (ERNST, 1985), so that a premature loss of needles may lead to a decreased input of Mn to the forest floor.

Soil acidification, in the sense of depletion of acid neutralizing capacity, may proceed for a long time without change in soil *p*H (VAN BREEMEN *et al.,* 1983); therefore, it is not surprising that soil *p*H in the present study did not differ between sites, although their acid neutralizing capacity may differ due to small differences in soil type. How soil acidity varies on a scale comparable to the microhabitat of soil invertebrates remains unknown.

Acidification of forest soils by simulated acid precipitation may lead to both negative and positive effects on various soil invertebrates (BÅÅTH *et al.,* 1980; HÅGVAR & AMUNDSEN, 1981; ABRAHAMSEN, 1983; HUHTA, 1984; HÅGVAR, 1984; HEUNGENS & VAN DAELE, 1984). Also, invertebrates may suffer directly from gaseous air pollution, although there appear to be large differences between species (LEBRUN *et al.,* 1978; LEETHAM *et al.,* 1982; ANDRÉ *et al.,* 1982; WHITE, 1983; WEIGMANN & KRATZ, 1987). According to HÅGVAR (1984), anthropogenically induced acidification of forest soils leads to community changes in favour of species with an already high dominance in naturally acid soils. The collembolan *Isotoma notabilis* seemed to be relatively acid-avoiding, as judged from its distribution in Norwegian forest soils (HÅGVAR & ABRAHAMSEN, 1984), and this was consistent with its decrease under experimental acidification (HÅGVAR, 1984). In our study area, hardly any *Isotoma notabilis* was present, although this species is abundant at various other places in the Netherlands; this may relate to the rather extreme situation in the Veluwe area with an average litter *p*H (H$_2$O) of 3.7. It is unknown whether sminthurids, which were found to correlate with vitality in this study, are more acid-sensitive than other Collembola. This family is a group of rather active, superficially living springtails, which, because of their drought-resistance, would seem to be less dependent on taking up free water than other Collembola. Therefore, a direct effect of soil *p*H does not seem probable for this group. Rather, results obtained in 1986 (VAN STRAALEN *et al.,* 1987) suggest that, with decreasing vitality there is an increase of total Collembola, without an increase of Sminthuridae. It would seem that other collembolan groups (Isotomidae, Entomobryidae) profit by acidification and thereby cause the proportion of sminthurids to decrease.

For the oribatid mite *Platynothrus peltifer,* experimental research (VAN STRAALEN *et al.,* 1987),

has shown that this species avoids acid substrates. Also, *P. peltifer* appears to have a markedly high body content of Fe and Mn, compared to Collembola: it has 10 times more Fe and 50 times more Mn than the collembolan *Orchesella cincta* [VAN STRAALEN *et al.*, 1987]. It would seem that, because of its acid sensitivity, and its high need for micronutrients such as Mn, *P. peltifer* is on the edge of its ecological amplitude in the Veluwe area, and is decreasing in abundance at those sites where the forest soil is critically depleted of nutrients and where preferred (relatively alkaline) microsites are becoming scarce. It is remarkable that the sites which take an intermediate position with respect to vitality (J, E and C) resemble the less vital sites more than the vital sites, when considered with respect to *P. peltifer* (fig. 5). Therefore, we conclude that this mite could be a valuable indicator species for monitoring changes in soil quality related to forest decline in an early stage.

5. Acknowledgements

6. References

ABRAHAMSEN, G., 1983. Effects of lime and artificial acid rain on the enchytraeid (Oligochaeta) fauna in coniferous forest. Hol. Ecol. **6**, 247−254.

ANDRÉ, H. M., C. BOLLY & PH. LEBRUN, 1982. Monitoring and mapping air pollution through an animal indicator: a new and quick method. J. Appl. Ecol. **19**, 107−111.

Anonymous, 1984. De vitaliteit van het Nederlands bos in 1984. Report 1984-26, Staatsbosbeheer, Utrecht.

ARNDT, U., G. SEUBERT & W. NOBEL, 1982. Die Beteiligung von Ozon an der Komplexkrankheit der Tanne (*Abies alba* MILL.) − eine prüfenswerte Hypothese. Staub. Reinh. Luft **42**, 243−247.

BÅÅTH, E., B. BERG, U. LOHM, B. LUNDGREN, H. LUNDKVIST, T. ROSSWALL, B. SÖDERSTRÖM & A. WIREN, 1980. Effects of experimental acidification and liming on soil organisms and decomposition in a Scots pine forest. Pedobiologia **20**, 85−100.

BOSATTA, E., 1982. Acidification and release of nutrients from organic matter − A model analysis. Oecologia (Berl.) **55**, 30−33.

BEWLEY, R. J. F., & G. STOTZKY, 1983. Simulated acid rain (H_2SO_4) and microbial activity in soil. Soil Biol. Biochem. **15**, 425−429.

BREEMEN, N. VAN, C. T. DRISCOLL & J. MULDER, 1984. Acidic deposition and internal proton sources in acidification of soils and waters. Nature **307**, 599−604.

− J. MULDER & C. T. DRISCOLL, 1983. Acidification and alkalinization of soils. Plant Soil **75**, 283−308.

BROWN, K. A., 1985. Acid deposition: effects of sulphuric acid at pH 3 on chemical and biochemical properties of bracken litter. Soil Biol. Biochem. **17**, 31−38.

CLAUSEN, H. S., 1986. The use of spiders (Araneae) as ecological indicators. Bull. Br. arachnol. Soc. **7**, 83−86.

ERNST, W. H. O., 1985. Schwermetallimmissionen − ökophysiologische und populationsgenetische Aspekte. Düsseldorfer Geobot. Kolloq. **2**, 43−57.

GISIN, H., 1960. Collembolenfauna Europas. Mus. Hist. Nat. Genève.

HÅGVAR, S., 1984. Effects of liming and artificial acid rain on Collembola and Protura in a coniferous forest. Pedobiologia **27**, 341−354.

− & G. ABRAHAMSEN, 1984. Collembola in Norwegian coniferous forest soils. III Relations to soil chemistry. Pedobiologia **27**, 331−339.

− & T. AMUNDSEN, 1981. Effects of liming and artificial acid rain on the mite (Acari) fauna in coniferous forest. Oikos **37**, 7−20.

HEUNGENS, A., & E. VAN DAELE, 1984. The influence of some acids, bases and salts on the mite and Collembola population of a pine litter substrate. Pedobiologia **27**, 299−311.

HOVLAND, J., G. ABRAHAMSEN & G. OGNER, 1980. Effects of artifical acid rain on decomposition of spruce needles and on mobilisation and leaching of elements. Plant Soil **56**, 365−378.

HUHTA, V., 1984. Response of *Cognettia sphagnetorum* (Enchytraeidae) to manipulation of pH and nutrient status in coniferous forest soil. Pedobiologia **27**, 245−260.

HÜTTL, R. F., 1985. Jüngste Waldschäden, Ernährungstörungen und diagnostische Düngung. VDI-Berichte **560**, 863−886.

KLEIN, T. M., N. J. NOVICK, J. P. KREITINGER & M. ALEXANDER, 1984. Simultaneous inhibition of carbon and nitrogen mineralization in a forest soil by simulated acid precipitation. Bull. Environ. Contam. Toxicol. **32**, 698−703.

LEBRUN, PH., J. M. JACQUES, M. GOOSSENS & G. WAUTHY, 1978. The effect of interaction between the concentration of SO_2 and the relative humidity of air on the survival of the bark-living bioindicator mite *Humerobates rostrolamellatus*. Water Air Soil Pollut. **10**, 269−275.

LEETHAM, J. W., T. J. McNARY, J. L. DODD & W. K. LAURENROTH, 1982. Response of soil nematodes, rotifers and tardigrades to three levels of season-long sulphur dioxide exposures. Water Air Soil Pollut. **17**, 343—356.

NIHLGÅRD, B., 1985. The ammonium hypothesis — An additional explanation to the forest dieback in Europe. Ambio **14**, 2—8.

ROELOFS, J. G. M., A. J. KEMPERS, A. L. F. M. HOUDIJK & J. JANSEN, 1985. The effect of air-borne ammonium sulphate on *Pinus nigra* var. *maritima* in the Netherlands. Plant Soil **84**, 45—51.

SELLNICK, M., 1960. Formenkreis: Hornmilben, Oribátei. *In:* P. BROHMER, P. EHRMANN, G. ULMER (eds.), Tierwelt Mitteleuropas, vol 3, IX. Quelle und Meyer, Leipzig, 1—42.

SOKAL, R. R., & F. J. ROHLF, 1981. Biometry. 2nd Ed. W. H. Freeman and Co, San Fransisco.

STRAALEN, N. M. VAN, M. GEURS & J. M. VAN DER LINDEN, 1987. Abundance, *p*H preference and mineral content of Oribatida and Collembola in relation to vitality of pine forests in the Netherlands. *In:* R. PERRY, R. M. HARRISON, J. N. B. BELL & J. N. LESTER (eds.), Acid Rain: Scientific and Technical Advances, Selper Ltd., London, pp. 674—679.

— & P. C. RIJNINKS, 1982. The efficiency of Tullgren apparatus with respect to interpreting seasonal changes in age structure of soil arthropod populations. Pedobiologia **24**, 197—209.

SWIFT, M. J., O. W. HEAL & J. M. ANDERSON, 1979. Decomposition in terrestrial ecosystems. Blackwell, Oxford.

ULRICH, B., 1983. A concept of forest ecosystem stability and of acid deposition as driving force for destabilization. *In:* B. ULRICH & J. PANKRATH (eds.), Effects of air pollutants in forest ecosystems. Reidel, Dordrecht, 1—29.

VERHOEF, H. A., & R. G. M. DE GOEDE, 1985. Effects of collembolan grazing on nitrogen dynamics in a coniferous forest. *In:* A. H. FITTER, D. ATKINSON, D. J. READ & M. B. USHER (eds.), Ecological-Interactions in Soil. Blackwell, Oxford, pp. 367—376.

— & F. G. DOREL, 1987. Effects of ammonia deposition on animal-mediated nitrogen mineralization and acidity in coniferous forest soils in the Netherlands. *In:* P. MATHY (ed.), Air pollution and ecosystems, Grenoble 1987, D. REIDEL Publ. Co., Dordrecht.

WEIGMANN, G., & W. KRATZ, 1987. Oribatid mites in urban zones of West Berlin. Biol. Fertil. Soils **3**, 81—84.

WHITE, J. J., 1983. Woodlice exposed to pollutant gases. Bull. Environ. Contam. Toxicol. **30**, 245—251.

ZÖTTL, H. W., 1985. Role of heavy metals in forest ecosystems. *In:* Proc. Int. Conf. Heavy Metals in the Environment, Athens 1985, Vol 1. CEP Consultants, Edinburgh, pp. 8—15.

Address of the authors: Dr. NICO M. VAN STRAALEN, Drs. MICHIEL H. S. KRAAK and Drs. CARL A. J. DENNEMAN, Biologisch Laboratorium, Vrije Universiteit, De Boelelaan 1087, Postbus 7161, 1007 MC Amsterdam, The Netherlands.

Synopsis: *Original scientific paper*

STRAALEN, N. M. VAN, M. H. S. KRAAK & C. A. J. DENNEMAN, 1988. Soil microarthropods as indicators of soil acidification and forest decline in the Veluwe area, the Netherlands. Pedobiologia **32**, 47—55.

A comparative study has been made of the abundance of various soil microarthropod groups in 12 coniferous forests within the Veluwe area, the Netherlands. Also, a number of nutrient elements in the A-horizon of the forest soil have been measured. Relationships between forest vitality (estimated by number of needle year-classes), abundance of microarthropods, and soil nutrient concentrations were studied by correlation analysis. The results show that the oribatid mite *Platynothrus peltifer* and the collembolan family Sminthuridae are most abundant (relative to total Oribatida and total Collembola) at the most vital sites and decrease as forest vitality decreases. This is correlated with a decrease of the Mn concentration and an increase of the C/N ratio of the litter. Microarthropods could be of value for indicating a decline of soil quality with consequent loss of forest vitality.

Key words: forest decline, soil acidification, manganese, nitrogen, C/N ratio, Oribatida, *Platynothrus peltifer*, Collembola, Sminthuridae.